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Environmental Effects of Dredging Technical Notes

REFINEMENT AND SIMPLIFICATION OF COLUMN SETTLING TESTS FOR DESIGN OF DREDGED MATERIAL CONTAINMENT AREAS

PURPOSE: This note provides background and theory concerning the settling of dredged material slurries, a description of the evolution of column settling test procedures, and the technical basis for certain simplifications to the test procedures that are not contained in other published reports.

This note does not repeat the detailed instructions for conducting column settling tests that are contained in the recently issued Engineer Manual (EM) 1110-2-5027, "Confined Disposal of Dredged Material" (Office, Chief of Engineers (OCE) US Army 1987).

BACKGROUND: Confined dredged material containment areas (DMCAs) must be designed to provide the storage volume required for both dredged solids and the removal of suspended solids from the effluent discharged from the area. Various settling processes occurring in the DMCA control the initial solids removal, compaction, and fractional retention of solids. EM 1110-2-5027 provides design guidance for DMCAs. Laboratory column settling tests are an integral part of these design procedures.

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Settling Processes in Dredged Material Disposal Areas

Four types of settling are generally recognized. The type that occurs in any given suspension is a function of both the type of particle involved, particularly its surface characteristics, and the concentration of particles at a given time. The four types are listed below.

I. Discrete Settling - The particles do not interact during settling. Each particle maintains its individuality and does not change in size, shape, or density while settling. Each particle settles as if it were alone and isolated.

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II. Flocculent Settling - The particles flocculate and agglomerate during settling. As the particles grow in size, they decrease in density because of entrained water, but they usually settle faster.

III. Zone Settling - The concentration of particles is so great that they touch adjacent particles in all directions and maintain their spatial relationship, settling as a mass or open matrix. They usually exhibit a definite interface between the settling particles and the clarified liquid above. The particle matrix settles more slowly than the individual particles of the same size and density because the quantity of water being displaced by the settling particles is so great that the resulting upward velocities of the displaced water reduce the effective downward velocity of the particle mass.

IV. Compression Settling - The concentration is so great that the particles rest on each other and mechanically support each other. The weight of the particles above slowly compresses the lower layers, increasing the pore pressure and squeezing out the water. This is also sometimes called thickening. In treatment plants, the settling is sometimes aided by slow stirring to break up the bridging action of the particles.

The relation of the different types of settling to type of particle and concentration of particles is shown in Figure 1.

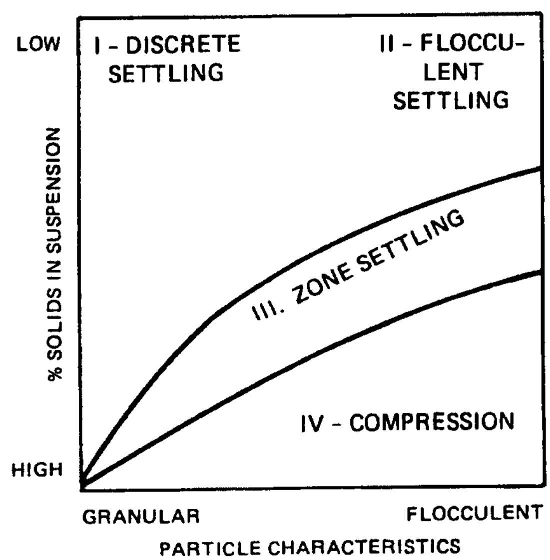

Figure 1. Types of settling

From Figure 1 it can be seen that discrete settling occurs only in suspensions with low concentrations of granular particles. This occurs in a DMCA with a small fraction of larger particles (sand and gravel) occasionally

encountered, or with bricks, crockery, shells, broken tools, and household items, etc., that were thrown or washed into the waterway. It never happens with hydraulically placed fine-grained dredged material, because the concentrations in the influent are so high (50 to 200 g/ℓ) and because most of the particles (clay, silt, organic matter) are naturally flocculent. All of the other three settling processes may occur simultaneously in a DMCA, and any one may control the design of the DMCA.

Dredged material slurries will initially exhibit either flocculent settling or zone settling, depending primarily on the slurry concentration, particle type, and the salinity of the water. Slurries with salinity greater than 3 ppt will usually exhibit zone settling, because the dissolved ions act as a coagulant. These ions compress the electrical double layer, reduce the effective distance over which the natural repulsive surface forces are effective, and allow sediment particles to touch enough adjacent particles that a loose open matrix is formed, which settles as a mass. Freshwater slurries usually exhibit flocculent settling, but may exhibit zone settling if concentrations are high enough or if the particle surface characteristics are flocculent enough.

Regardless of whether the upper layers of the settling material in the containment area initially exhibit flocculent or zone settling, the bottom layers of settled material will exhibit compression settling, or thickening. As material accumulates and the concentration rises, successive layers will begin to rest on and be supported by the bottom of the disposal area and then each other, much like an accordion being slowly let down onto a hard surface. The change from flocculent or zone settling to compression settling, at which the bottom begins to provide some physical support, occurs at a concentration of approximately 200 to 300 g/ℓ for most dredged material slurries.

Development of Procedures

The development of initial guidance for designing DMCAs was described by Montgomery (1978); Montgomery, Thackston, and Parker (1983); and Palermo, Montgomery, and Poindexter (1978). Montgomery (1978) developed laboratory test procedures for characterizing the settling properties of dredged material slurries and provided step-by-step instructions and example design calculations. These procedures allow the prediction of the concentration of

suspended solids in the effluent of a DMCA in which flocculent settling is occurring. The effluent from a DMCA in which zone settling is occurring (the clarified supernatant above the interface) was said to contain less than 1 g/ℓ, but no procedure to quantify it further was suggested.

Palermo (1984, 1986) and Palermo and Thackston (in preparation) extended the work of Montgomery by applying the flocculent settling tests to the particles in the supernatant above the interface. These procedures may be used to predict the concentration of particles in the effluent to within a few milligrams per liter.

Field verification of these laboratory tests, along with the results from project studies and the experience of both WES and Corps District personnel in using the laboratory test and design procedures, is described by Averett, Palermo, and Wade (in preparation). These studies, plus additional simplifications and refinements described in this technical note, led to the testing and design procedures now contained in EM 1110-2-5027 (OCE 1987). The procedures originally recommended by Montgomery (1978) for designing DMCAs to ensure sufficient solids storage capacity, based on the results of the long-term compression settling test, have not been changed, and are included in EM 1110-2-5027 in their original form.

Testing Column

Both Montgomery's (1978) work with dredged material slurries and the pioneering work of Vesilind (1968) showed conclusively that wall effects in small columns will greatly affect the settling rate, sometimes positively and sometimes negatively, depending on solids concentrations and characteristics. Montgomery's (1978) work showed that 20 cm (8 in.) was the smallest diameter column in which settling would be comparable to that occurring in the field. A schematic of the standard testing column recommended by Montgomery is shown in Figure 2.

Pilot Test

The earlier works of Montgomery (1978) and Palermo, Montgomery, and Poindexter (1978) provided guidance on how to conduct both zone settling and flocculent settling tests on the bulk slurries, and how to distinguish between

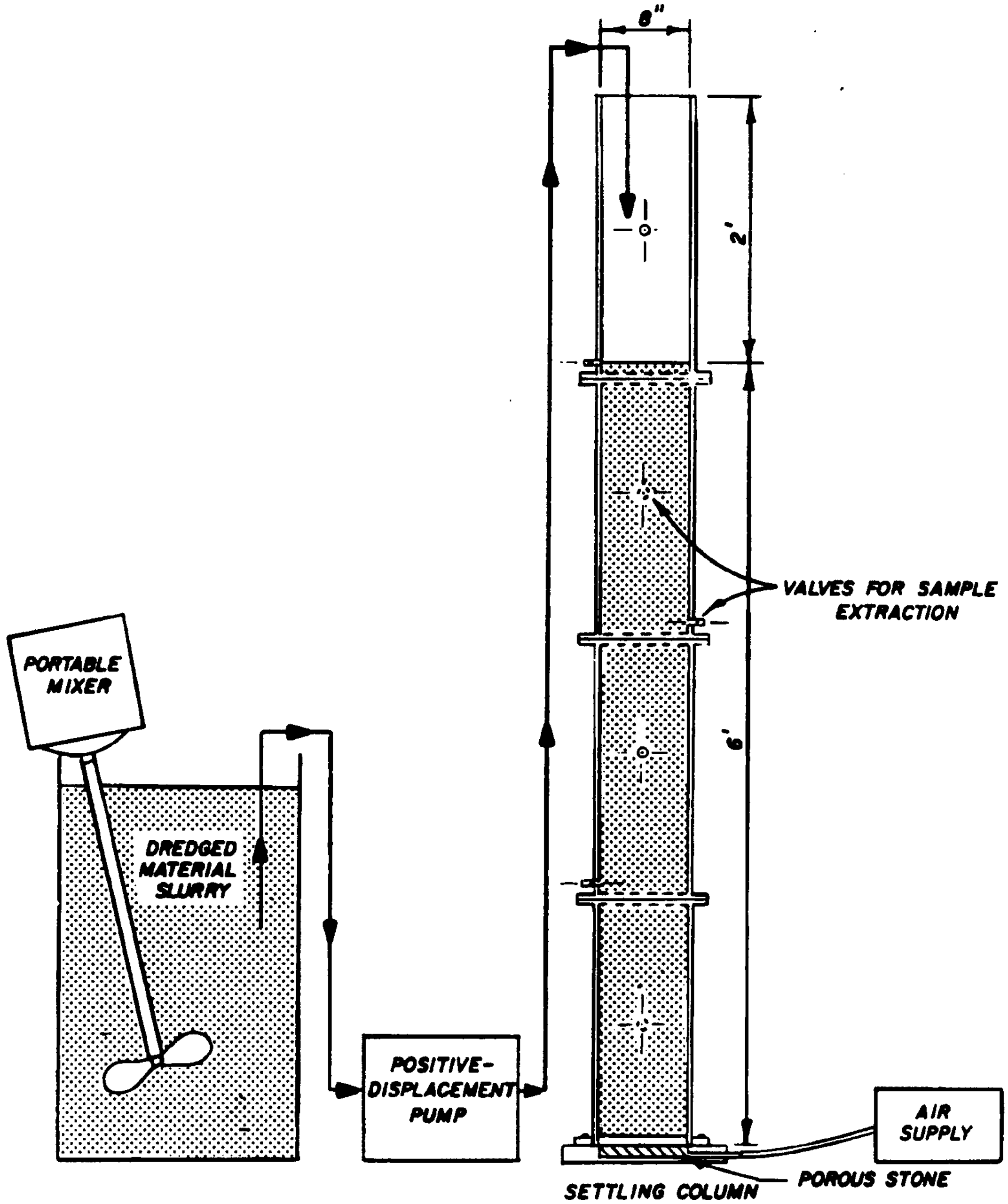

Figure 2. Schematic of apparatus for settling tests

them once the lab test had begun. (Zone settling produces a sharp interface.) However, no method to predict which type of settling would occur was discussed, other than the observation that saltwater sediments usually exhibited zone settling and freshwater sediments usually exhibited flocculent settling.

EM 1110-2-5027 recommends the use of a pilot test in a 4-ℓ graduated cylinder before the main test in the 20-cm column is conducted. This pilot

test allows lab personnel to identify the type of settling occurring, to estimate how many suspended solids determinations will need to be conducted, to estimate how many samples will need to be taken simultaneously (during a flocculent settling test, four to six samples, but during a zone settling test, only one to three samples above the interface), and to decide what kind of data analysis will be needed. With this information, sufficient supplies can be procured, oven space reserved, etc., before the full-scale test begins.

It is important to remember that settling rates observed in the 4-ℓ test cylinder are not representative of those to be expected in the field, although the settling processes should be. EM 1110-2-5027 recommends a 4-ℓ graduated cylinder because it is the largest standard size "small" vessel readily available. A smaller cylinder could be used, but wall effects would be much more severe, and settling rates would be even less representative of actual field conditions.

Simplification of Zone Settling Test

For the case of zone settling of the slurry, the test developed by Montgomery (1978) consists of the following stages:

a. Placing the slurry in the settling column.

b. Observing the fall of the interface formed between the semiclarified supernatant and the more concentrated slurry.

c. Repeating the test several times using a specific range of slurry concentrations.

d. Computing the limiting solids flux for zone settling using procedures described by Yoshioka et al. (1957).

These procedures have been simplified in EM 1110-2-5027 so that only one zone settling test is now required. The single test is to be conducted at the slurry concentration expected in the influent to the DMCA in the field (the highest average concentration expected to prevail for several hours at a time), or at 150 g/ℓ if the expected influent concentration is not known. This should produce a sufficiently conservative design, since zone settling velocities are inversely proportional to slurry concentration, and 150 g/ℓ is the highest average concentration usually encountered for several hours at a time. The technical basis for the simplification is given in the following paragraphs.

This recommendation of a single test is a significant simplification compared to the original procedure (Montgomery 1978; Palermo, Montgomery, and Poindexter 1978). The original procedure required a series of zone settling tests with initial slurry concentrations ranging from 50 to 200 g/ℓ. The results from these tests were used to calculate the solids flux (lb/hr-ft^2),

$$S_i = C_i v_i$$

where C_i (lb/ft^3) is the slurry concentration and v_i (ft/sec) is the zone settling velocity, so that a plot of solids flux versus slurry concentration could be made as recommended by Yoshioka et al. (1957). This plot, shown as Figure 3, was used to find the limiting solids flux, S_L, as a function of the selected design solids concentration, C_d, to be achieved in the lower layers of the DMCA at the end of the filling operation. The value of C_d is determined from the compression settling test and is the average solids concentration in the containment area at the end of the dredging operation.

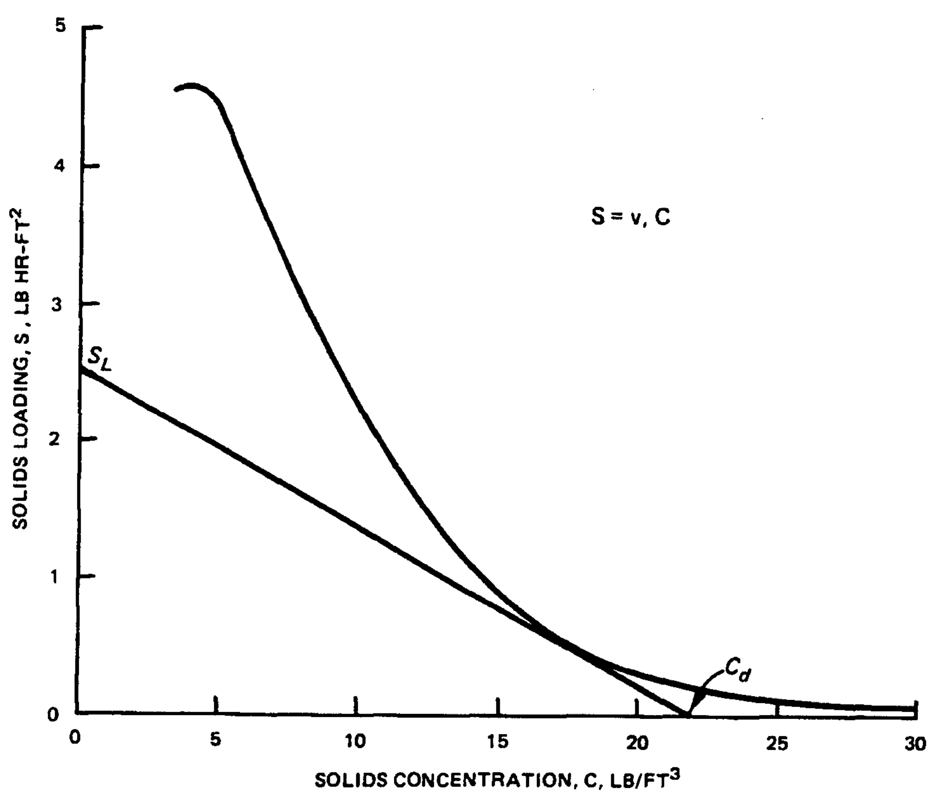

Figure 3. Typical solids loading curve for dredged material

The value of S_L is determined by drawing a line from C_d on the horizontal axis tangent to the solids flux curve and intersecting the solids loading scale on the ordinate as shown in Figure 3.

This is a standard design procedure used in environmental engineering practice for continuous thickeners, in which C_d represents the desired underflow concentration. A very good explanation of this procedure was given by Dick (1972).

In applying this procedure to DMCAs, in which there is no underflow, the implicit assumption was made that the average concentration of material in the containment area at the end of dredging, C_d, could be used to represent the underflow concentration. This assumption does not imply that the "bottom" (the boundary between the zone settling phase and the compression or thickening phase) will be stationary and not rise during filling of the DMCA as occurs in a continuous thickener, in which the depth of settled solids is kept constant. A stationary interface could occur only if there were a downward velocity created by an underflow equivalent to the upward movement of the boundary between phases caused by the continual addition of more solids settling from above. Selection of a limiting solids loading only limits the upward movement of the boundary to a tolerable amount. Since bottom buildup is controlled by storage volume design, not settling velocity, this precaution and the attendant elaborate design procedure have now been found to be unnecessary in most cases.

First, zone settling velocity is usually not the limiting factor in sizing a DMCA. Solids storage capacity usually is. Second, it has been found that it is unnecessary to limit the rate of rise of the "bottom." All that is necessary to prevent unacceptably high effluent solids concentrations is that solids be removed from the overlying surface water and deposited on the "bottom" faster than (or at least as fast as) the maximum rate at which they can be transported downward by zone settling. This criterion may be met by using the minimum value of solids flux produced by the maximum probable value of influent slurry concentration as used in the lab test.

If the "bottom" elevation rises far enough to cause the "clarified" surface layer to be too shallow for effective solids removal (because of high advective flow velocities or wind-generated turbulence in the too-shallow surface layer), the elevation of the water surface can be raised, adding to the thickness of the surface layer. This can easily be done by adding boards

to the adjustable-height outlet weir if the dikes have been correctly designed to be strong enough and high enough for the expected solids volume plus settling volume plus freeboard.

In addition, there are frequently situations in which Montgomery's (1978) design procedure cannot be applied. For some slurries, C_d is so close to (not much greater than) C_i , the influent slurry concentration, that a tangent to the solids flux curve cannot be drawn. This occurs when the influent slurry concentration is high, but thickens slowly, so that the design solids concentration, or solids concentration at the bottom of the test column at a time equal to one-half the expected time of filling of the DMCA, is below the steeply sloping part of the solids flux curve.

Referring to Figure 3, one can see that, if the design solids concentration from the long-term consolidation test were 12.5 lb/ft^3, no tangent to the solids flux curve could be drawn. If the design solids concentration were 15 lb/ft^3, the tangent line could be drawn, but would produce an intercept on the ordinate, or value of S_L , that is so high that it is meaningless, because it is higher than any possible value on the solids flux curve.

Extension of Flocculent Settling Test

For the case of flocculent settling of the slurry, the tests developed by Montgomery (1978) generally consist of the following steps:

- a. Placing the slurry in the settling column at the expected influent solids concentration.
- b. Extracting samples of the settling slurries at various times and at various depths in the column.
- c. Analyzing the samples for solids concentrations.
- d. Computing the weighted fractions of solids removed at each sampling time by settling using procedures described by McLaughlin (1959).

EM 1110-2-5027 recommends no changes in the regular flocculent settling test devised by Montgomery (1978). This test is similar to the standard multiheight column settling test common in environmental engineering, but uses a much simpler and more straightforward method of analysis that was originally proposed by McLaughlin (1959). However, EM 1110-2-5027 does contain an extension of the flocculent settling test to the semiclarified supernatant above the interface in zone settling tests, based on the work of Palermo (1984).

When slurries undergo zone settling in a laboratory test column, almost

all of the solids are entrapped in a loose, open matrix that settles as a single mass. However, a few colloidal solids that are not trapped in the matrix remain in the semiclarified supernatant above the interface. In addition, as the mass settles, it displaces water from below, which must move upward through the voids in the settling mass. This upward water velocity shears some loosely bound colloids from the settling mass and carries them into the supernatant, causing the suspended solids concentration to rise during the initial stages of settling. The higher the slurry concentration, the smaller the void spaces, the higher the resulting upward water velocities, and the more solids that are carried into the semiclarified supernatant.

Montgomery (1978) did not propose any method of quantifying the total suspended solids (TSS) concentration in the supernatant, which in a DMCA becomes the effluent concentration. He only stated that the effluent concentration from DMCAs designed using his procedure and properly operated should be below 1 to 2 g/ℓ, low enough to satisfy most of the effluent discharge permit standards common at that time. However, many current discharge permits limit effluent TSS to below 0.1 g/ℓ, so this approach is not sufficient. Therefore, Palermo (1984) devised a method to predict the TSS in the supernatant as a function of retention time, based on the application of the flocculent settling test.

Palermo (1984, 1986) showed that the solids in the supernatant always undergo flocculent settling, whether the slurry undergoing zone settling is from fresh water or salt water. He also showed that the normal flocculent test procedures could be used, except that there is no true initial concentration to be used to calculate normalized concentrations. As explained above, there are two sources of solids in the supernatant under laboratory test conditions--one (the solids not originally trapped in the settling mass) decreasing with time because of flocculation and settling, and one (the solids carried into the supernatant from the settling mass by the upward-flowing displaced water) increasing with time.

Palermo (1984, 1986) analyzed the effects of several possible assumptions regarding the magnitude of the value to be used as the initial concentration in the laboratory test, and showed that all gave essentially the same final result. Therefore, he recommended that, for simplicity, the concentration in the first sample taken at the highest sampling port be used as the initial concentration.

Summary

Several additions and modifications have been made to the recommended column settling test and design procedures for dredged material containment areas since the first guidance was published (Montgomery 1978; Palermo, Montgomery, and Poindexter 1978). These changes have been incorporated into the procedures described in the newly issued design manual, EM 1110-2-5027. This technical note provides the design engineer with an explanation of the major changes and why they were made. The engineer is referred to the EM itself for a detailed outline of the procedures.

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